How design efficiency, operation and occupant behavior impact the Building Energy Use

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Outline

ITRI introduction
- Who is ITRI?
- Green energy and environment laboratories

Source energy end use
- DOE commercial Large office building
- Operation and design efficiency characters
- Building database benchmarking

Occupant behavior analysis
- Austerity
- Standard
- Wasteful

ITRI introduction

ITRI- Industrial Technology Research Institute
A not-for-profit R&D institution founded in 1973

- To **create economic value** through innovated technology and R&D
- To **spearhead the development** of emerging high-tech industry
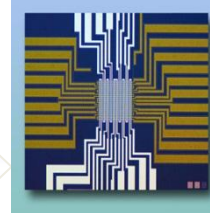- To **enhance the competitiveness** of industries in the global market

14 research units

6 focused lab.

Total Employer：5,808

- Ph.D. — 22%
- Master — 55%
- Bachelor — 14%
- Technical School — 7%
- Others — 2%

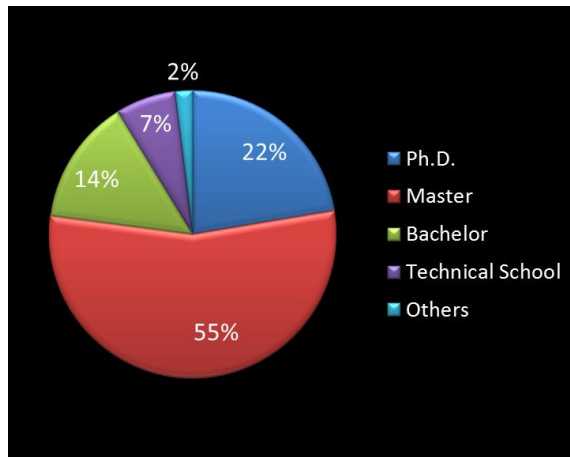Information and Communications Technologies

Electronics and Optoelectronics

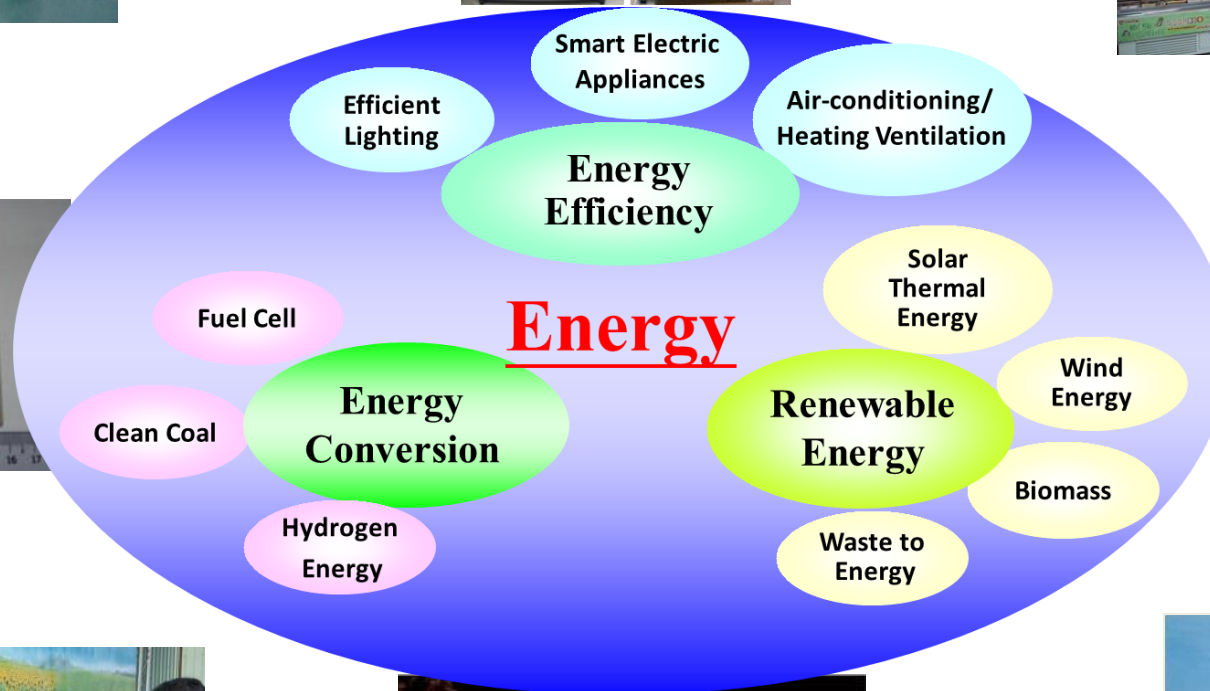Medical device and biomedical

Nanotechnology, Materials and Chemicals

Mechanical and Systems

Green Energy and Environmental
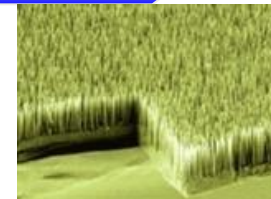
Green Energy & Environment Lab.

Energy

- Smart Electric Appliances
- Efficient Lighting
- Air-conditioning/ Heating Ventilation
- **Energy Efficiency**
- Fuel Cell
- Clean Coal
- **Energy Conversion**
- Hydrogen Energy
- Solar Thermal Energy
- Wind Energy
- **Renewable Energy**
- Biomass
- Waste to Energy

Technologies

Policy, Programs

Integrated Design — Architect & Engineer Sense

Low Energy Buildings

Appliance Standards

Operation & Maintenance — Operator adjust method

Building Energy Code & Labeling

Usage — Occupant Behavior

Source energy end use overview

2010 U.S. Commercial Source Energy Use Splits

Lighting, 3.2
Space Heating, 2.52
Space Cooling, 1.86
Ventilation, 1.6
Refrigeration, 1.23
Electronics, 0.82
Water Heating, 0.79
Computers, 0.66
Cooking, 0.25
Other, 2.53
Adjust to SEDS, 2.89
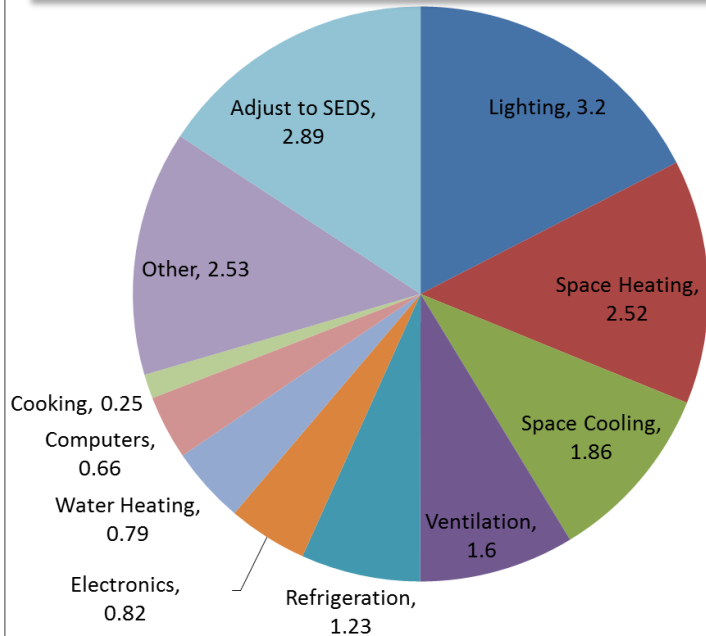
Total: 18.35 Quadrillion Btu

Source energy use forecast

10.6
13.4
17.2
18.5
18.4
18.9
20.2
21.4
22.8
24.0

30%

Primary Energy use(Quadrillion Btu)

Year
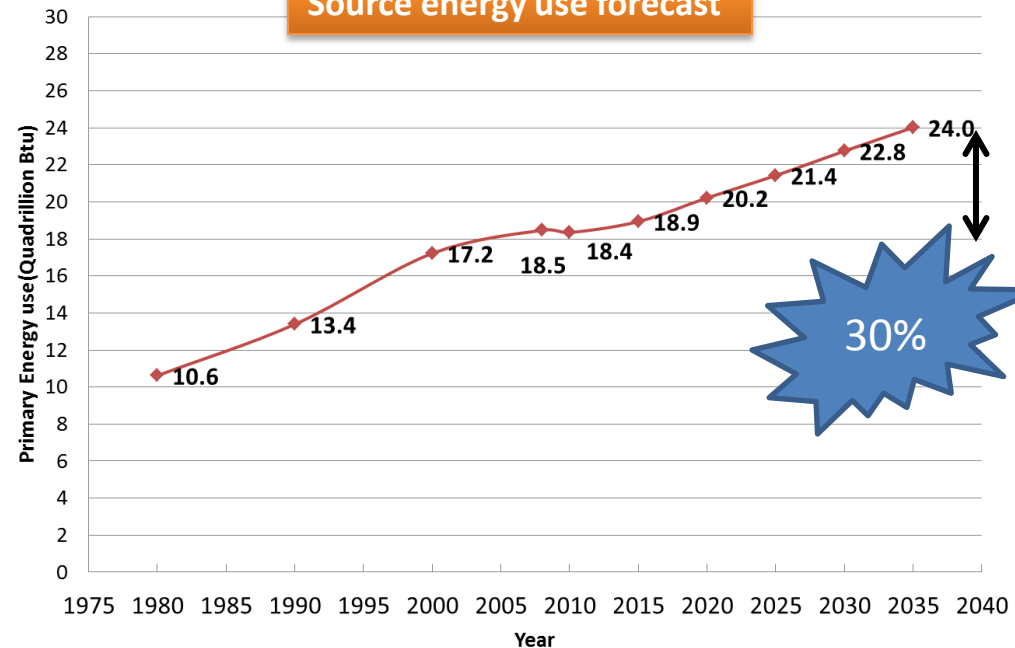
Data Source: USDOE 2010 Buildings Energy Databook

Goal:

- Identify and quantify impact of key building design and operation parameters on energy performance of office buildings

- Compare simulated and measured energy performance of buildings to better understand the discrepancies between them

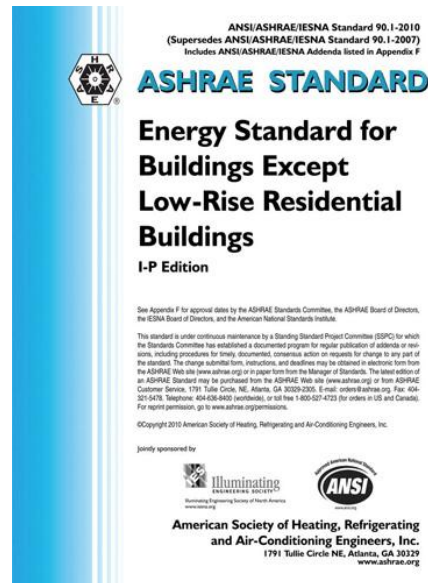- How building operation practice and occupant behavior influence energy use of buildings

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Approach

- Parametric Analysis
  - Start with the large office from the USDOE commercial reference buildings
  - Vary potential key design and operation parameters
  - Look at source energy of the whole building
  - Select five cities in typical climates
  - Use EnergyPlus Version 6 and TMY3 weather data
- Compare Simulation Results with "Measured Data"
  - CBECS, 2003 Commercial building energy consumption survey
  - CEUS, California commercial energy use survey (March 2006)
  - HPB, USDOE high performance buildings (1984-2009)

The Large Office Building

Key Characteristics

- Total floor area 46,320 m^2
- 12 stories + basement
- 30% perimeter zone area
- 40% window-wall-ratio (WWR)
- Rectangle shape with aspect ratio is 1.5
- Built-up VAV with water-cooled chiller and gas boiler
- Energy efficiency levels are based on ASHRAE Standard 90.1-2004

ANSI/ASHRAE/IESNA Standard 90.1-2010
(Supersedes ANSI/ASHRAE/IESNA Standard 90.1-2007)
Includes ANSI/ASHRAE/IESNA Addenda listed in Appendix F

ASHRAE STANDARD

Energy Standard for Buildings Except Low-Rise Residential Buildings

I-P Edition

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle NE, Atlanta, GA 30329
www.ashrae.org
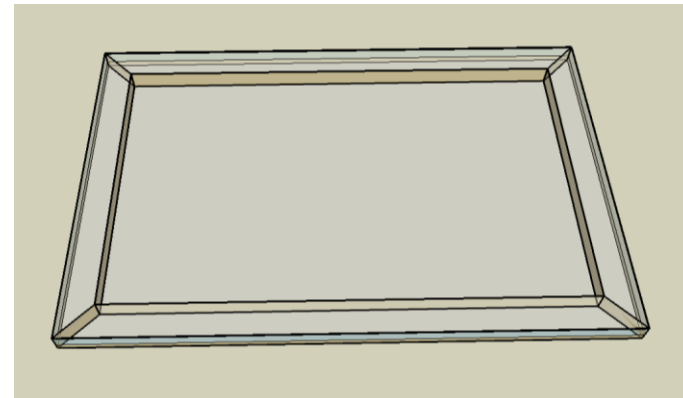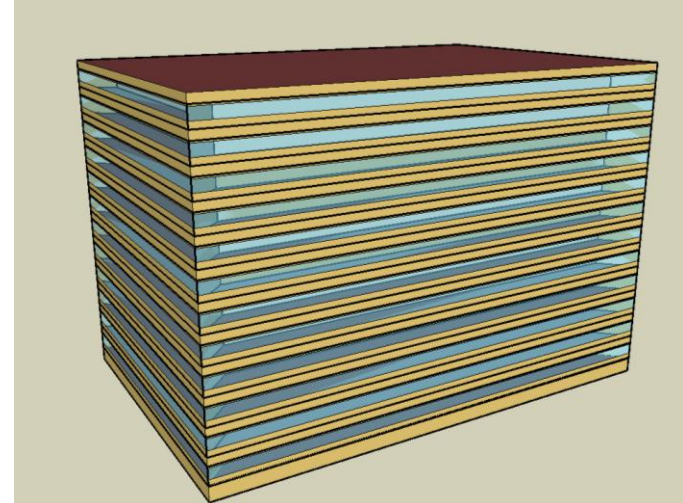
Selected Cities and Climates

City	ASHRAE Climate Zones		CBECS Census Regions	HDD18	CDD10
Miami	1A	Very Hot –Humid	South Atlantic, South	200	9474
San Francisco	3C	Warm-Marine	Pacific, West	3016	2883
Chicago	5A	Cool-Humid	West-North Central, Midwest	6176	3251
Minneapolis	6A	Cold-Humid	East-North Central, Midwest	7981	2680
Fairbanks	8	Subarctic	Hi, West	13940	1040
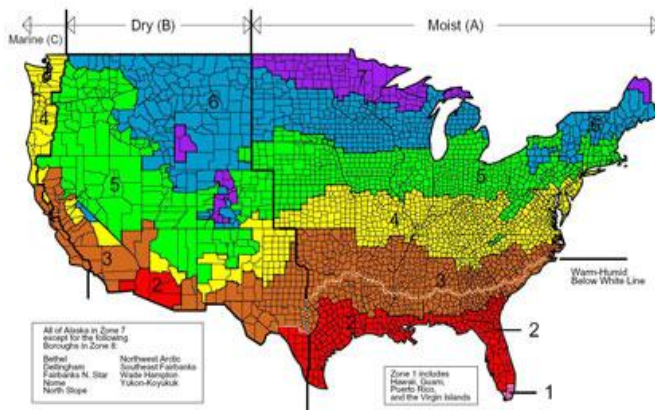
ASHRAE Climate Zones
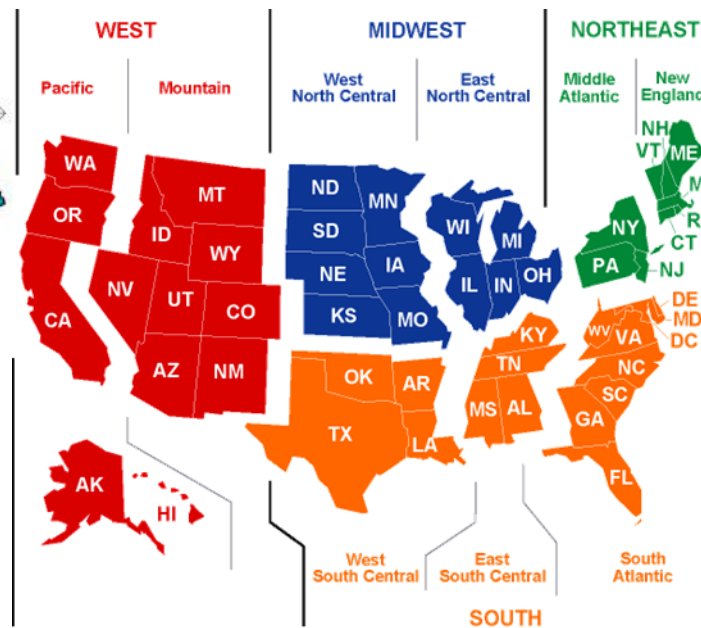
CBECS Census Regions
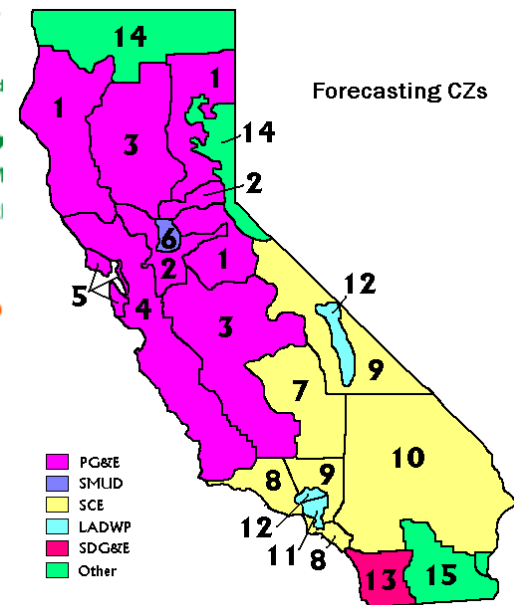
CEUS Regions

Building Operating Schedules
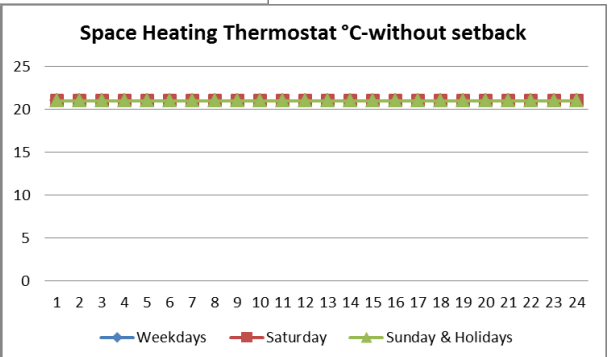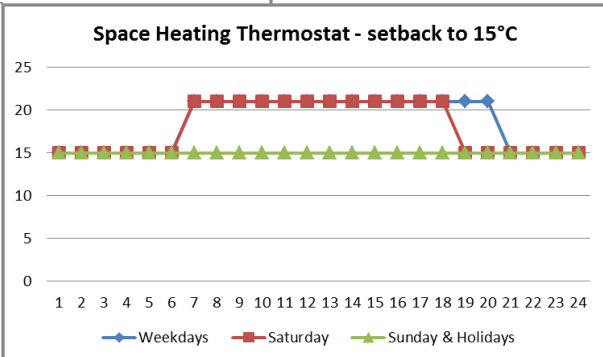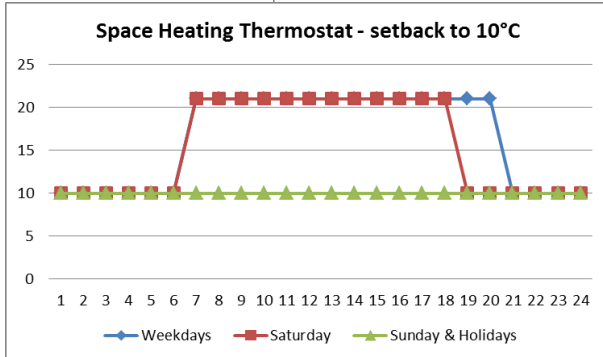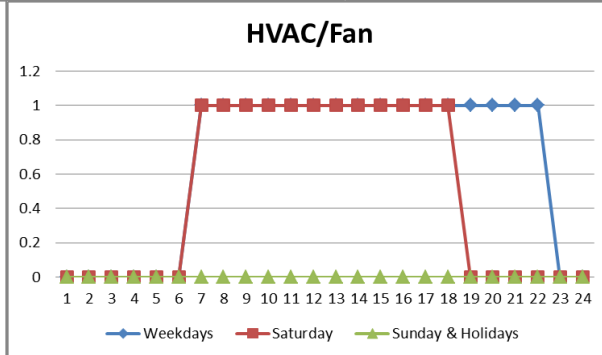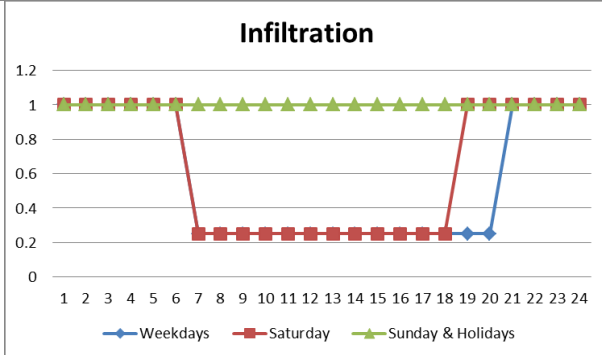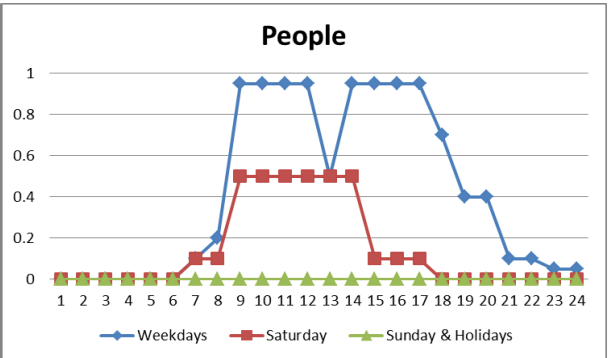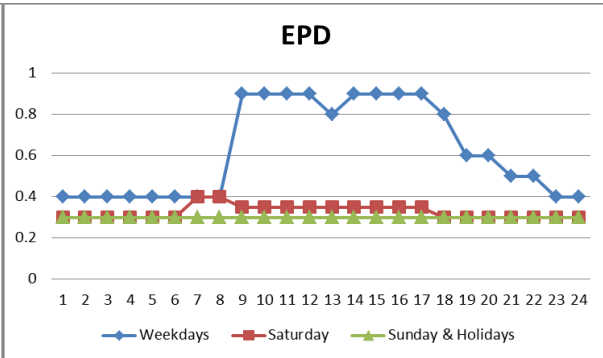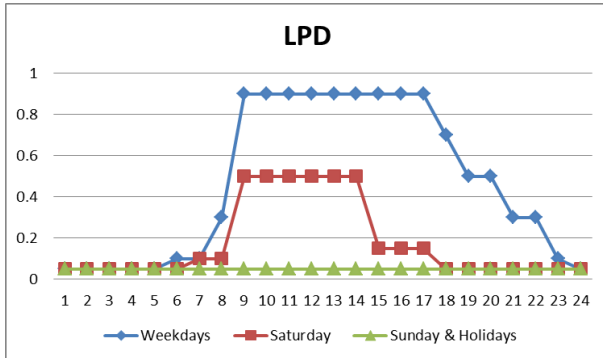
Key Parameters

Design parameters/efficiency	Operation parameters
Window area	Daylighting control
Window construction	Shading control
Insulation	Infiltration rate
• Wall insulation	Infiltration schedule
• Roof insulation	VAV box damper setting
Internal load	Heating thermostat
• Lighting power density	Cooling thermostat
• Equipment power density	Heating setback during unoccupied hours
Economizer	Cooling setback during unoccupied hours
Chiller efficiency	Supply air temperature reset
Boiler efficiency	Lighting schedule
Fan efficiency	Plug-load schedule
Occupant density	

Design Key Parameters

	High Performance	Basecase	Low performance
Window area	10%	40%	68%
Window construction	Triple pane	ASHRAE Standard 90.1-2004	Single pane
Wall and roof Insulation	ASHRAE Standard 90.1-2010	ASHRAE Standard 90.1-2004	no insulation
Lighting power density (LPD)	state-of-art lighting technologies (50% Low)	ASHRAE Standard 90.1-2004	ASHRAE Standard 90.1-1989 (50% high)
Equipment power density (EPD)	Paper, published in ACEEE 2006 (30% Low)	ASHRAE Standard 90.1-2004	Same as LPD level (50% high)
Boiler Efficiency	ASHRAE Standard 90.1-2010 (91%)	ASHRAE Standard 90.1-2004 (78%)	(65%): Training Manual on Energy Efficiency Asian Productivity Organization, 2010
Chiller Efficiency	(COP=7.0):	ASHRAE Standard 90.1-2004 (COP=5.5):	(COP=4):
Fan Efficiency	Advanced Variable Air Volume System Design Guide, Pier, 2005 (66.5%)	ASHRAE Standard 90.1-2004 (60%)	Advanced Variable Air Volume System Design Guide, Pier, 2005 (46.8%)
Occupant Density	NBI report, 2011 37.2 m^2/person	18.6 m^2/person: ASHRAE Standard 90.1-2004	NBI report, 2011 12.1 m^2/person

Operation Key Parameters

	High Performance	Basecase	Low performance
Infiltration rate	NIST report (50% low)	ASHRAE Standard 90.1-2004	NIST report (188% high)
Infiltration schedule	0% for occupied hour 100% for unoccupied hour	25% for occupied hour 100% for unoccupied hour ASHRAE Standard 90.1-2004	100% on whole day
VAV box damper setting	15%	ASHRAE Standard 90.1-2004 (30%)	50%
Heating Setpoint (^{o}C)	18	ASHRAE Standard 90.1-2004 (21)	23
Heating setback during unoccupied hours (^{o}C)	15	ASHRAE Standard 90.1-2004 (no setback)	10
Cooling Setpoint (^{o}C)	26	ASHRAE Standard 90.1-2004 (24)	22
Cooling setback during unoccupied hours (^{o}C)	30	ASHRAE Standard 90.1-2004 (no setback)	26
Lighting Schedule	ASHRAE Research Project 1093-RP, 2001 (FTEH=8.8)	ASHRAE Standard 90.1-2004 (FTEH=11.3)	ASHRAE Research Project 1093-RP, 2001 (FTEH=19.4)
Plug-load Schedules	ASHRAE Research Project 1093-RP, 2001 (FTEH=9.2)	ASHRAE Standard 90.1-2004 (FTEH=15)	ASHRAE Research Project 1093-RP, 2001 (FTEH=17.5)

Key Parameters (cont'd)

Shading Control

- Venetian blinds: blind on and fully closed, blind on with slats controlled to block beam solar
- Basecase no shading

Airside Economizer

- No economizer
- Basecase may have economizer (DifferentialDryBulb) depending on climate zones

Supply Air Temperature Setpoint

- Reset by outdoor air temperature
- Reset by the warmest zone
- Basecase :no reset

Weather Data

- Multiple year weather data: 1980 to 2009

Daylighting Control

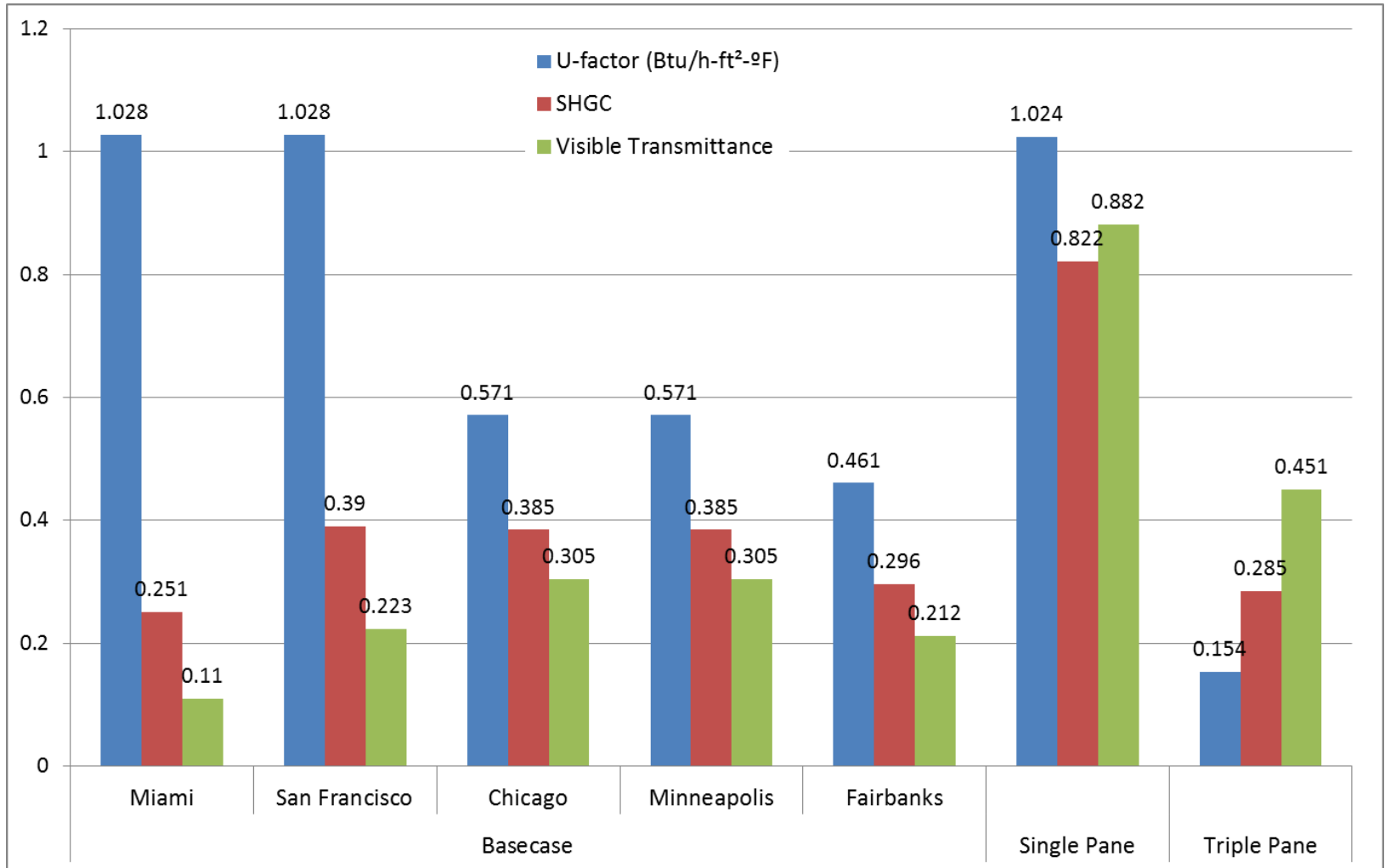- Continuous dimming control
- Basecase without daylighting control

Parametric of the Simulation Runs

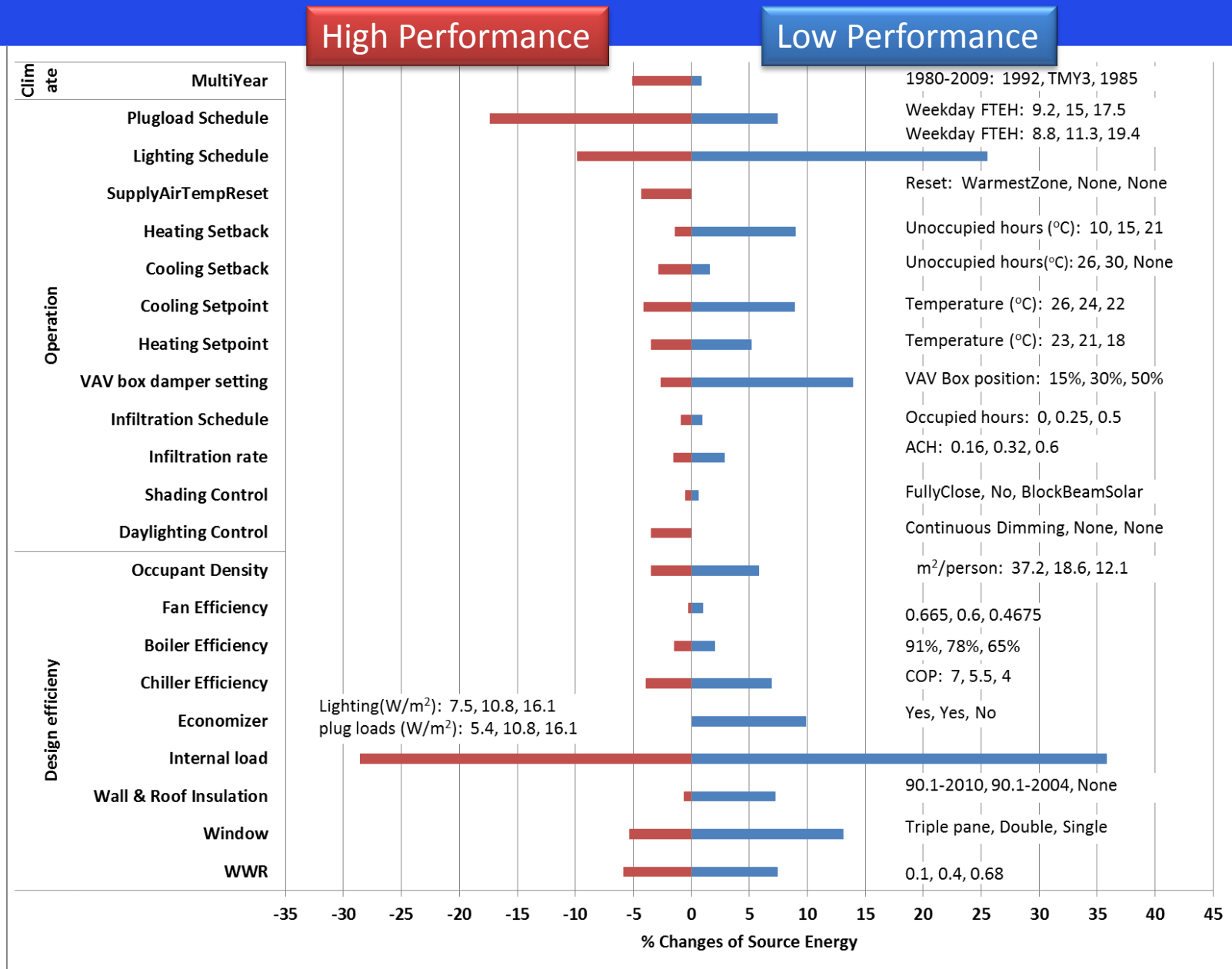| Description	LPD/EPD (W/m²)	Chiller /Boiler Efficiency	Fan Efficiency	WWR	Occupant Density (m²/person)	Infiltration Rate (ach)	Infiltration Schedule	Min Air Flow Fraction	Heating setpoint/ Setback (ºC)	Cooling Setpoint/ Setback (ºC)	Roof /wall insulation	Window
Basecase (90.1-2004)	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High Internal Loads (50% higher)	16.14/16.14	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low Internal Loads (50% lower)	7.53/5.38	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High WWR	10.76/10.76	5.5/78%	0.6	0.68	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low WWR	10.76/10.76	5.5/78%	0.6	0.1	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High Infiltration Rate (188% higher)	10.76/10.76	5.5/78%	0.6	0.4	18.6	2.44	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low Infiltration Rate (50% lower)	10.76/10.76	5.5/78%	0.6	0.4	18.6	0.64	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High Infiltration Schedule	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	1	0.3	21/15	24/30	90.1-2004	90.1-2004
Medium Infiltration Schedule	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.5	0.3	21/15	24/30	90.1-2004	90.1-2004
High Min. Air Flow Fraction	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.5	21/15	24/30	90.1-2004	90.1-2004
Low Min. Air Flow Fraction	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.15	21/15	24/30	90.1-2004	90.1-2004
High Chiller Efficiency	10.76/10.76	7.0/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low Chiller Efficiency	10.76/10.76	4.0/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High Boiler Efficiency	10.76/10.76	5.5/91%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low Boiler Efficiency	10.76/10.76	5.5/65%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High Fan Efficiency	10.76/10.76	5.5/65%	0.665	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low Fan Efficiency	10.76/10.76	5.5/65%	0.4675	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004

Parametric of the Simulation Runs (cont'd)

Description	LPD/EPD (W/m²)	Chiller /Boiler Efficiency	Fan Efficiency	WWR	Occupant Density (m²/person)	Infiltration Rate (ach)	Infiltration Schedule	Min Air Flow Fraction	Heating setpoint/ Setback (°C)	Cooling Setpoint/ Setback (°C)	Roof /wall insulation	Window
High Occupant Density	10.76/10.76	5.5/78%	0.6	0.4	12.1	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
Low Occupant Density	10.76/10.76	5.5/78%	0.6	0.4	37.2	1.28	0.25	0.3	21/15	24/30	90.1-2004	90.1-2004
High Heating Setpoint	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	23/15	24/30	90.1-2004	90.1-2004
Low Heating Setpoint	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	18/15	24/30	90.1-2004	90.1-2004
Heating Setback to 10°C	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/10	24/30	90.1-2004	90.1-2004
Heating no setback	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/21	24/30	90.1-2004	90.1-2004
High Cooling Setpoint	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	26/30	90.1-2004	90.1-2004
Low Cooling Setpoint	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	22/30	90.1-2004	90.1-2004
Cooling Setback to 26°C	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/26	90.1-2004	90.1-2004
Cooling no setback	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/24	90.1-2004	90.1-2004
No insulation	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	No insulation	90.1-2004
More insulation	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2010	90.1-2004
Single Pane Windows	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	Single Pane
Triple Pane Windows	10.76/10.76	5.5/78%	0.6	0.4	18.6	1.28	0.25	0.3	21/15	24/30	90.1-2004	Triple Pane
Worst case	16.14/16.14	4.0/65%	0.4675	0.68	12.1	2.44	1	0.5	23/23	24/24	90.1-2004	Single Pane
Best case	7.53/5.38	7.0/91%	0.665	0.1	37.2	0.64	0.25	0.15	18/10	26/30	90.1-2004	Triple Pane

Window Constructions

Chicago (Source Energy EUI of Basecase: 1.39 GJ/m^2)

High Performance | Low Performance

Category	Parameter	Values
Climate	MultiYear	1980-2009: 1992, TMY3, 1985
Operation	Plugload Schedule	Weekday FTEH: 9.2, 15, 17.5
	Lighting Schedule	Weekday FTEH: 8.8, 11.3, 19.4
	SupplyAirTempReset	Reset: WarmestZone, None, None
	Heating Setback	Unoccupied hours (°C): 10, 15, 21
	Cooling Setback	Unoccupied hours(°C): 26, 30, None
	Cooling Setpoint	Temperature (°C): 26, 24, 22
	Heating Setpoint	Temperature (°C): 23, 21, 18
	VAV box damper setting	VAV Box position: 15%, 30%, 50%
	Infiltration Schedule	Occupied hours: 0, 0.25, 0.5
	Infiltration rate	ACH: 0.16, 0.32, 0.6
	Shading Control	FullyClose, No, BlockBeamSolar
	Daylighting Control	Continuous Dimming, None, None
Design efficieny	Occupant Density	m^2/person: 37.2, 18.6, 12.1
	Fan Efficiency	0.665, 0.6, 0.4675
	Boiler Efficiency	91%, 78%, 65%
	Chiller Efficiency	COP: 7, 5.5, 4
	Economizer	Yes, Yes, No
	Internal load	Lighting(W/m^2): 7.5, 10.8, 16.1 plug loads (W/m^2): 5.4, 10.8, 16.1
	Wall & Roof Insulation	90.1-2010, 90.1-2004, None
	Window	Triple pane, Double, Single
	WWR	0.1, 0.4, 0.68

% Changes of Source Energy

-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45

18

Minneapolis (Source Energy EUI of Basecase 1.42 GJ/m^2)

Fairbanks (Source Energy EUI of Basecase: 1.44 GJ/m²)

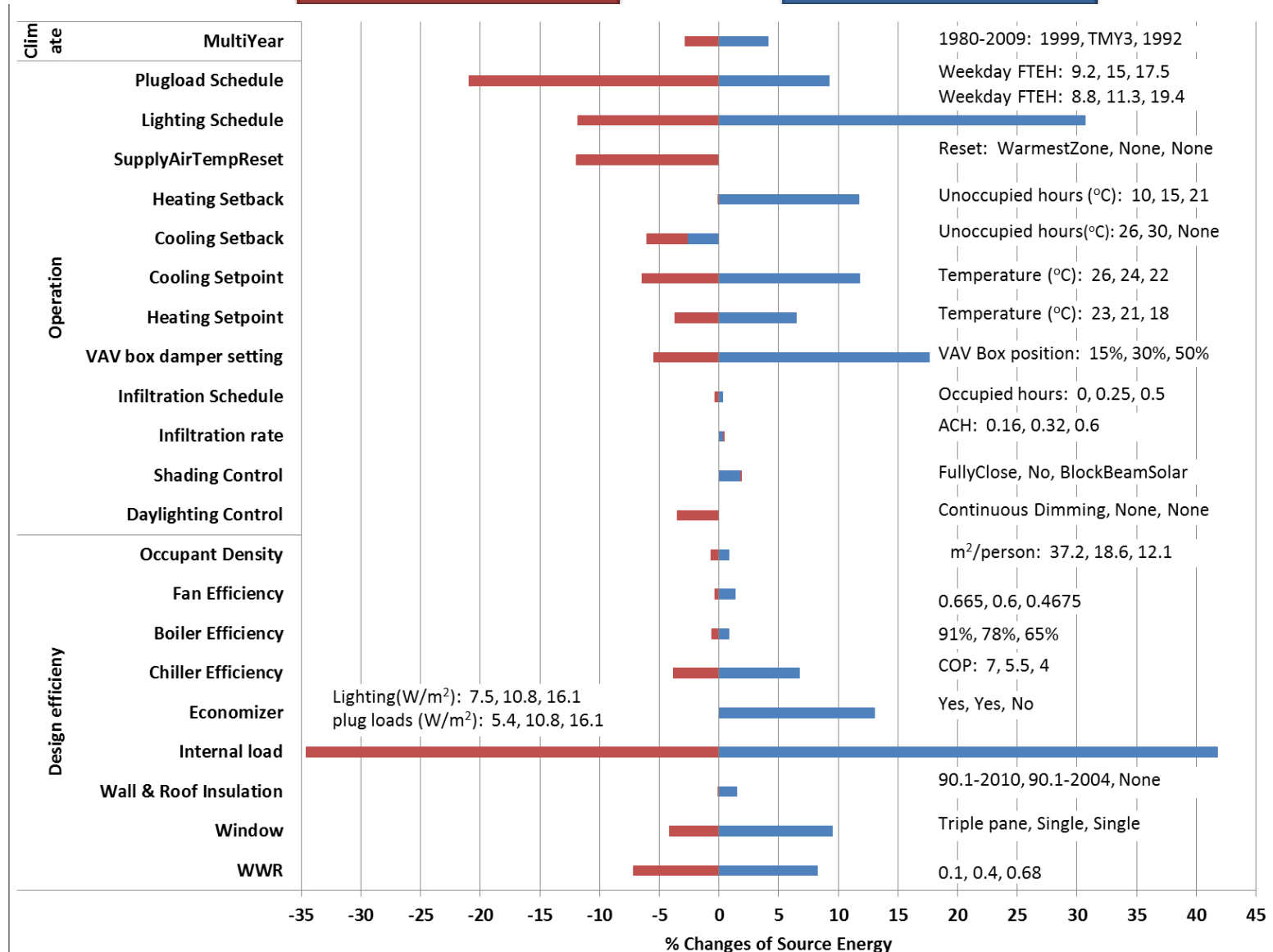# Miami (Source Energy EUI of Basecase: 1.69 GJ/m^2)

High Performance | **Low Performance**

Category	Parameter	Settings
Climate	MultiYear	1980-2009: 1981, TMY3, 1998
Operation	Plugload Schedule	Weekday FTEH: 9.2, 15, 17.5
	Lighting Schedule	Weekday FTEH: 8.8, 11.3, 19.4
	SupplyAirTempReset	Reset: WarmestZone, None, None
	Heating Setback	Unoccupied hours (^{o}C): 10, 15, 21
	Cooling Setback	Unoccupied hours(^{o}C): 26, 30, None
	Cooling Setpoint	Temperature (^{o}C): 26, 24, 22
	Heating Setpoint	Temperature (^{o}C): 23, 21, 18
	VAV box damper setting	VAV Box position: 15%, 30%, 50%
	Infiltration Schedule	Occupied hours: 0, 0.25, 0.5
	Infiltration rate	ACH: 0.16, 0.32, 0.6
	Shading Control	FullyClose, No, BlockBeamSolar
	Daylighting Control	Continuous Dimming, None, None
Design efficiency	Occupant Density	m^2/person: 37.2, 18.6, 12.1
	Fan Efficiency	0.665, 0.6, 0.4675
	Boiler Efficiency	91%, 78%, 65%
	Chiller Efficiency	COP: 7, 5.5, 4
	Economizer	Yes, Yes, No
	Internal load	Lighting(W/m^2): 7.5, 10.8, 16.1; plug loads (W/m^2): 5.4, 10.8, 16.1
	Wall & Roof Insulation	90.1-2010, 90.1-2004, None
	Window	Triple pane, Double, Single
	WWR	0.1, 0.4, 0.68

% Changes of Source Energy

21

San Francisco (Source Energy EUI of Basecase: 1.27 GJ/m²)

High Performance | **Low Performance**

Category	Parameter	Values (High, Base, Low)
Climate	MultiYear	1980-2009: 1999, TMY3, 1992
Operation	Plugload Schedule	Weekday FTEH: 9.2, 15, 17.5
	Lighting Schedule	Weekday FTEH: 8.8, 11.3, 19.4
	SupplyAirTempReset	Reset: WarmestZone, None, None
	Heating Setback	Unoccupied hours (°C): 10, 15, 21
	Cooling Setback	Unoccupied hours(°C): 26, 30, None
	Cooling Setpoint	Temperature (°C): 26, 24, 22
	Heating Setpoint	Temperature (°C): 23, 21, 18
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	Chiller Efficiency	COP: 7, 5.5, 4
	Economizer	Yes, Yes, No
	Internal load	Lighting(W/m²): 7.5, 10.8, 16.1; plug loads (W/m²): 5.4, 10.8, 16.1
	Wall & Roof Insulation	90.1-2010, 90.1-2004, None
	Window	Triple pane, Single, Single
	WWR	0.1, 0.4, 0.68

% Changes of Source Energy

Climate Variability

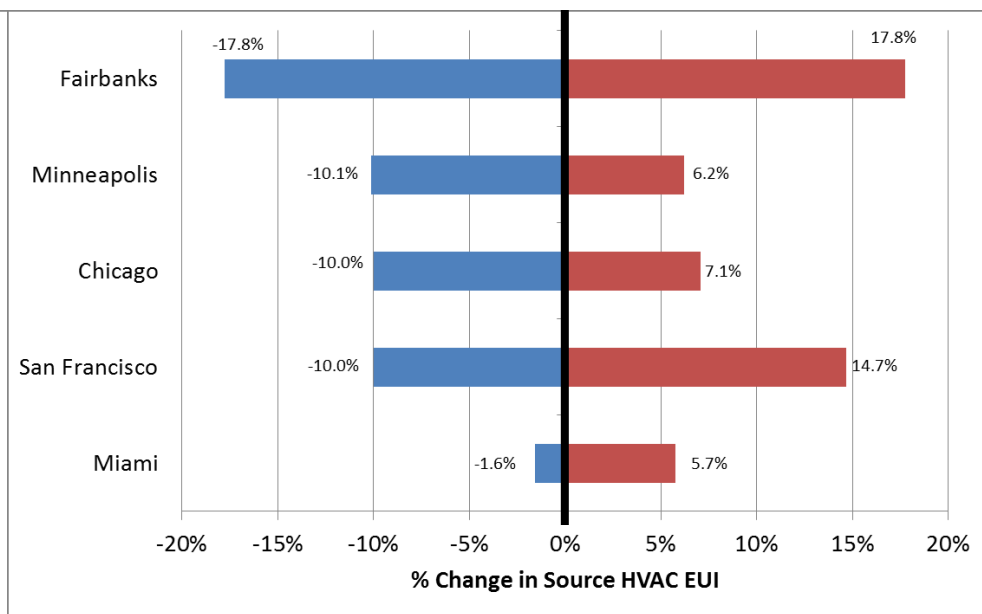**Wall and roof insulation**

Boiler efficiency
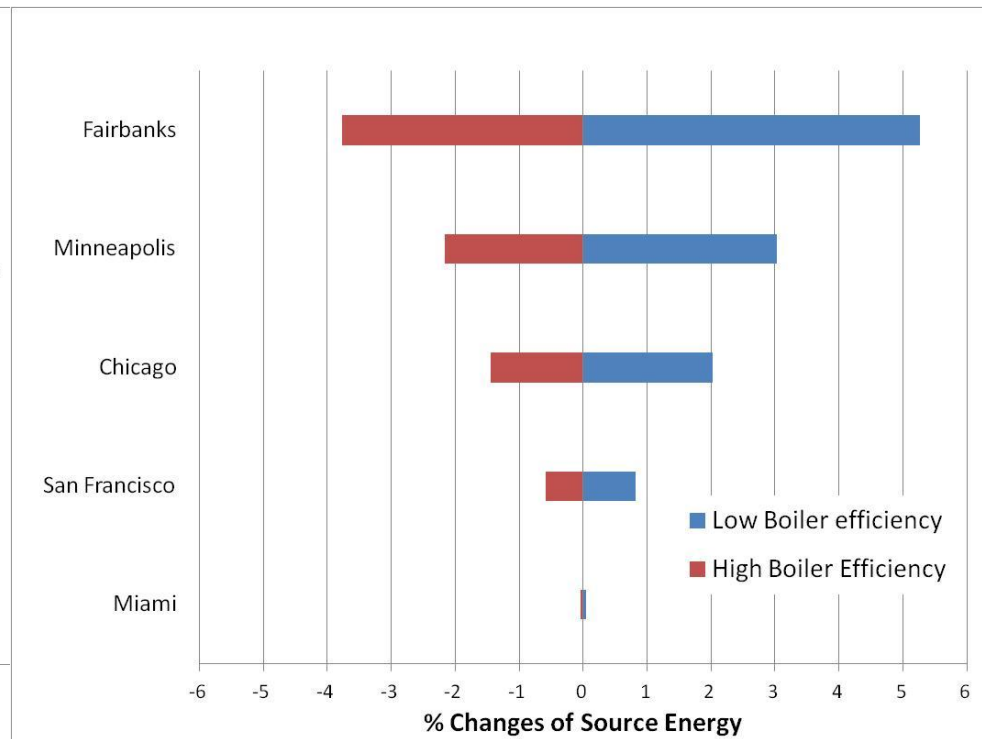
Multi-year Variable (1980-2009)

Source energy use comparison
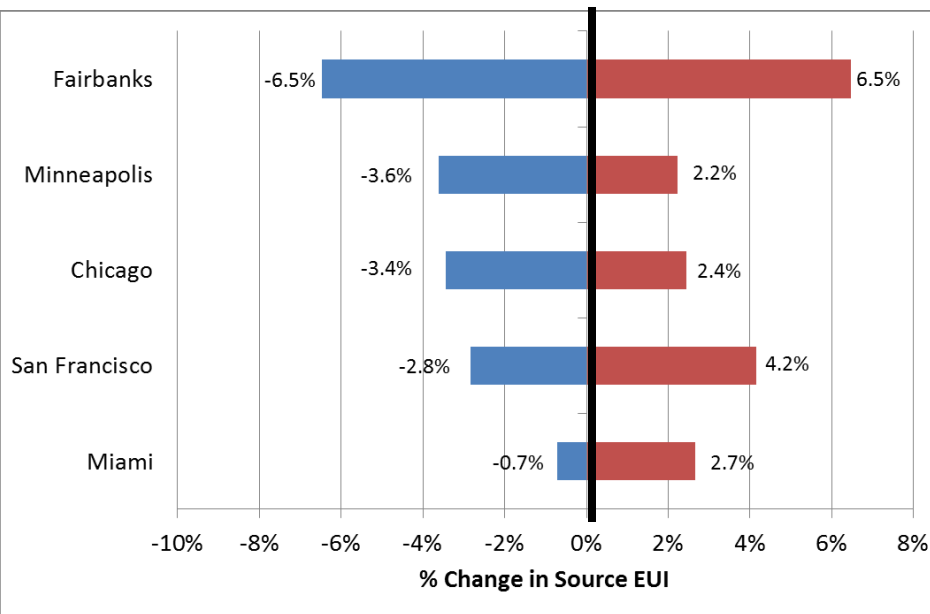
Source energy use comparison for HVAC

Selected Office Buildings in the Databases

HPB ID	Code	Climate	Map	Region	Building Vintage	Floor area (SF)	Number of Buildings	Source energy (GJ/m²)	Source energy distributions
	1A	Miami	CBECS	South Atlantic, South	1990-2003	200,001-1,000,000	5	1.9 to 4.3	1.9, 3.4, 3.6, 4, 4.3
	3C	San Francisco	CBECS	Pacific of West	1990-2003	200,001-1,000,000	2	2.2 to 2.5	2.2, 2.5
	5A	Chicago	CBECS	East-North Central of Midwest	1990-2003	200,001-1,000,000	9	1.46 to 5.94	1.46, 2.4, 2.6, 2.8, 3.0, 4.2, 5.94
	6A	Minneapolis	CBECS	West-North Central of Midwest	1990-2003	>100,001	3 (1 if between 200k and 1000k)	2.3-3.3	2.3, 3.0, 3.3
	3C	San Francisco	CEUS	PG&E5 (Itron)	1990-2006	>30,000	1	2.29	
	3C	San Francisco	CEUS	PG&E5 (Itron)	1990-2006	<30,000	1	2.78	
	3C	San Francisco	CEUS	North Coast (Energy IQ)	1990-2006	>150,000	1	1.4	
817	3C	San Francisco	HPB	Berkeley, CA	2006	94,500	1	4.46	4.46
97	5A	Chicago	HPB	Chicago IL	2003	40,000	1	0.65	0.65

Best Case and Worst Case

-65.7% ⟷ 290.9%

-66.3% ⟷ 283.3%

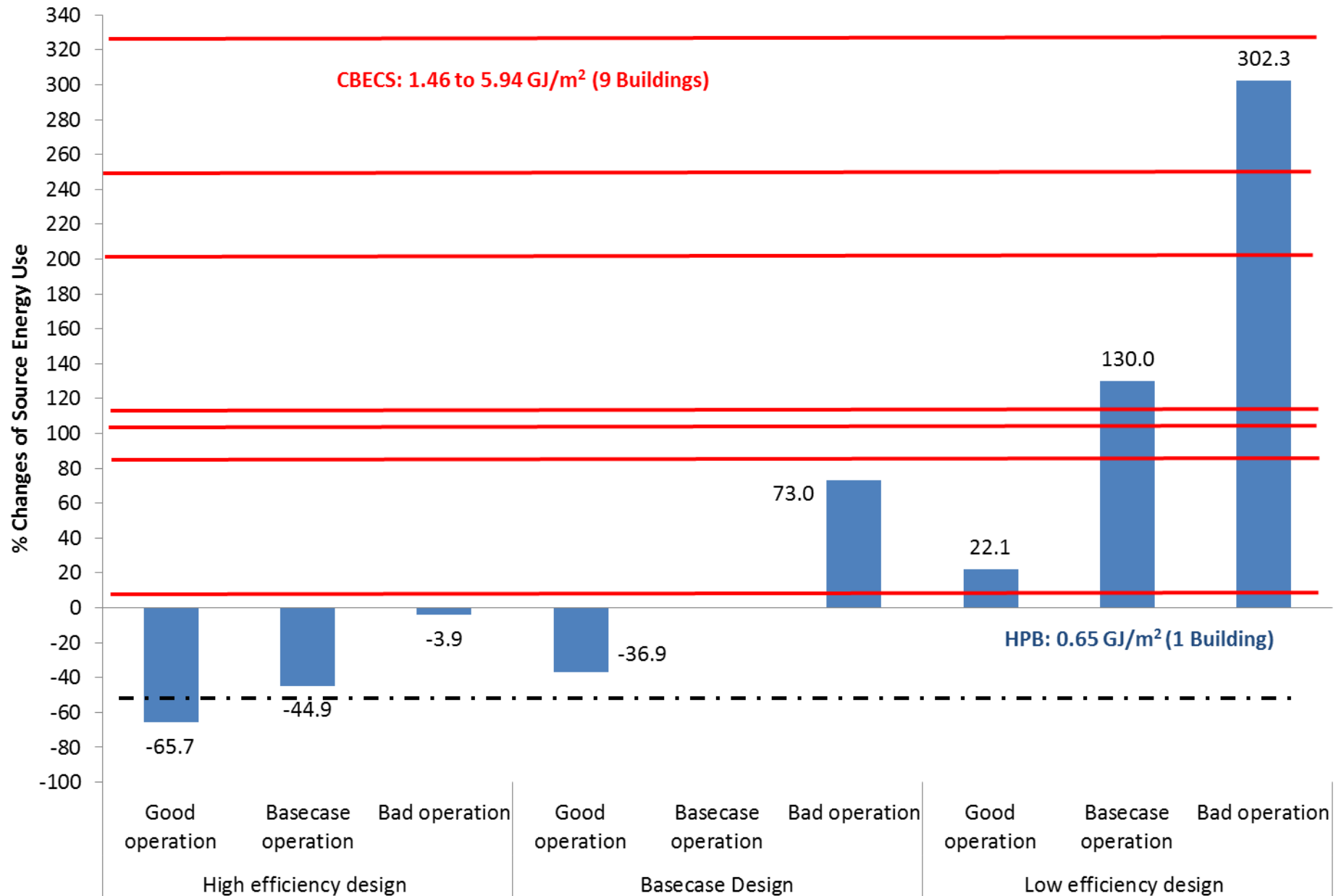**Large Office in Chicago (Source Energy EUI of Basecase: 1.39 GJ/m²)**

Large Office in San Francisco (Source Energy EUI of Basecase 1.27 GJ/m²)
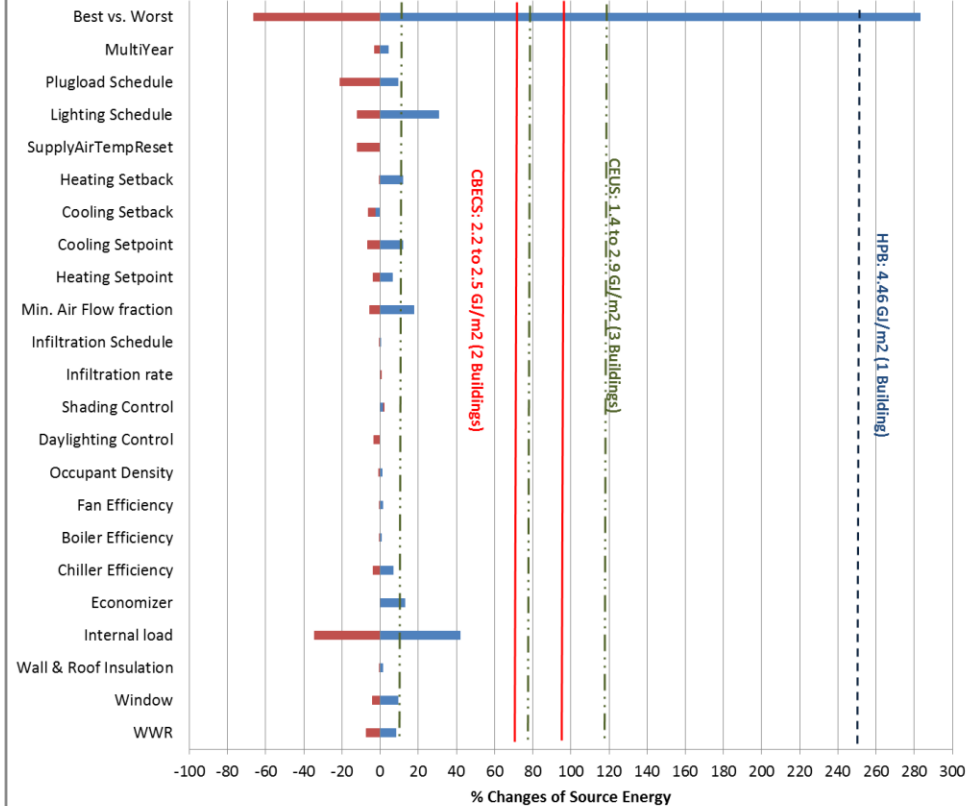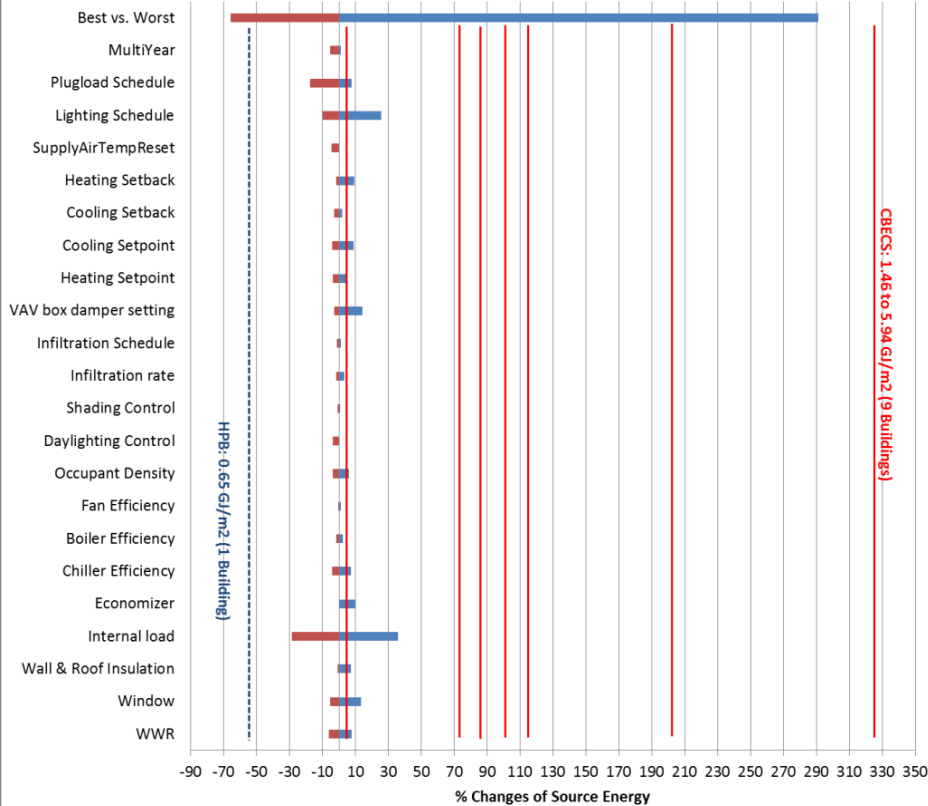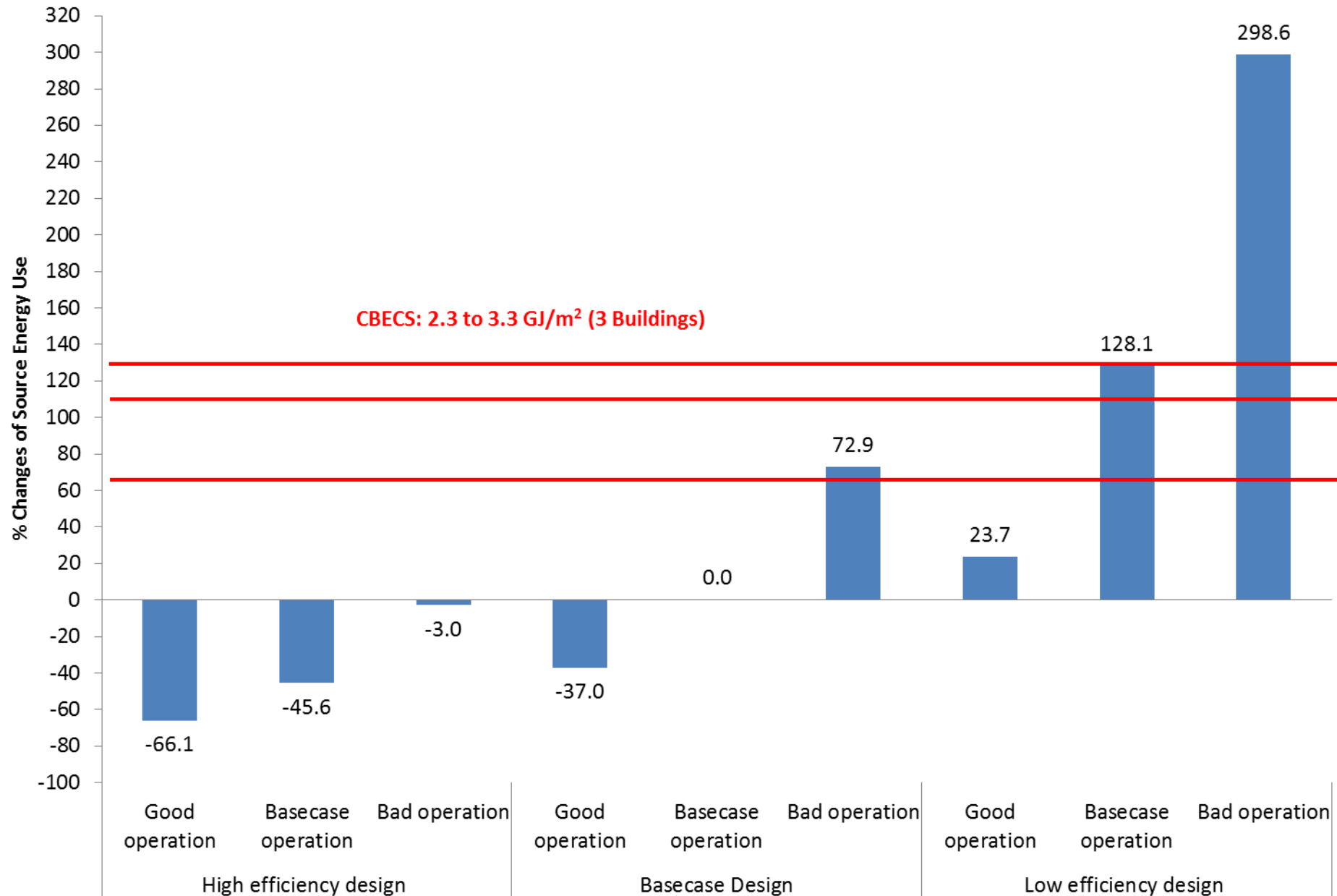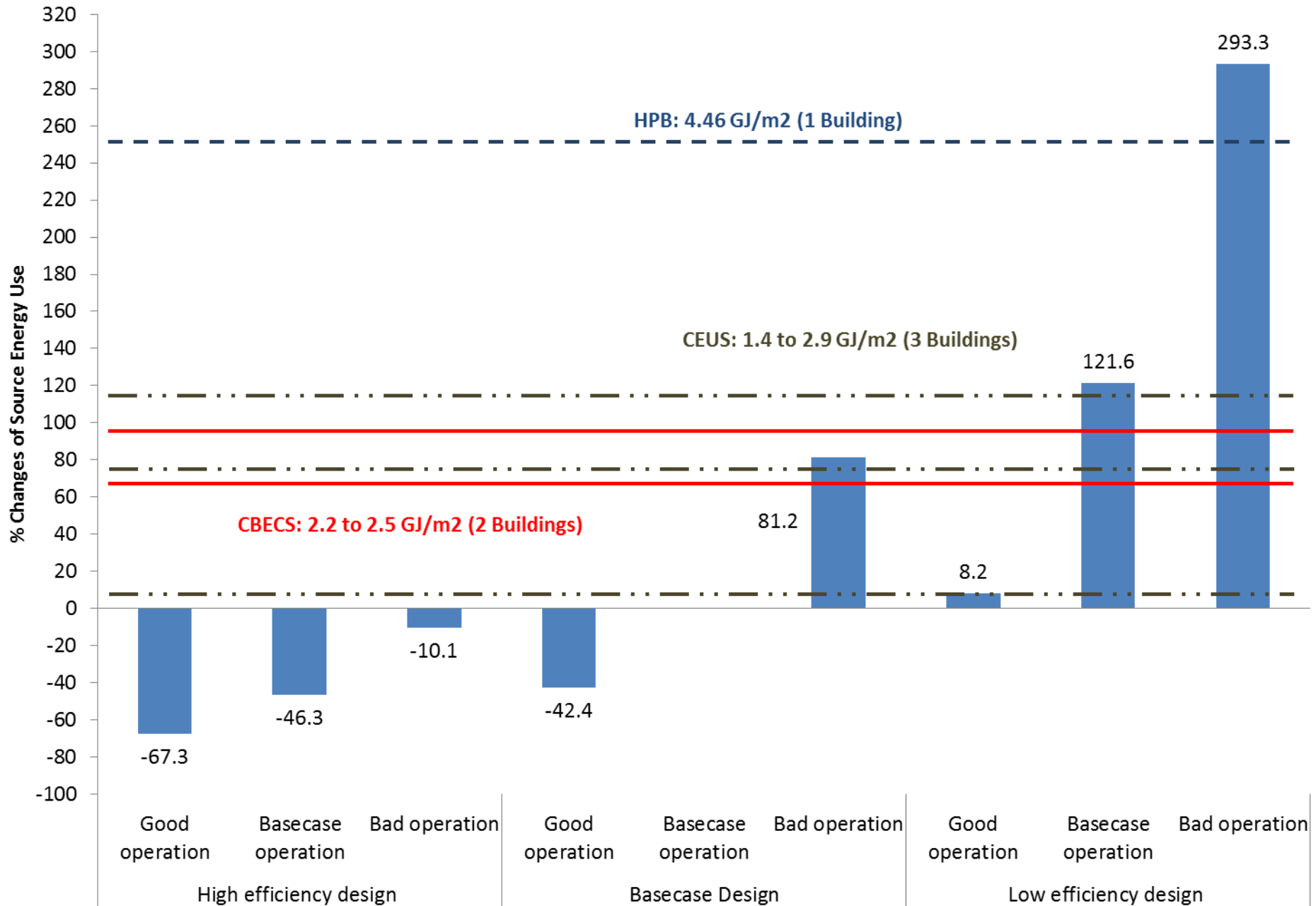
Chicago

San Francisco

Chicago (Source Energy EUI of Basecase: 1.39 GJ/m^2)

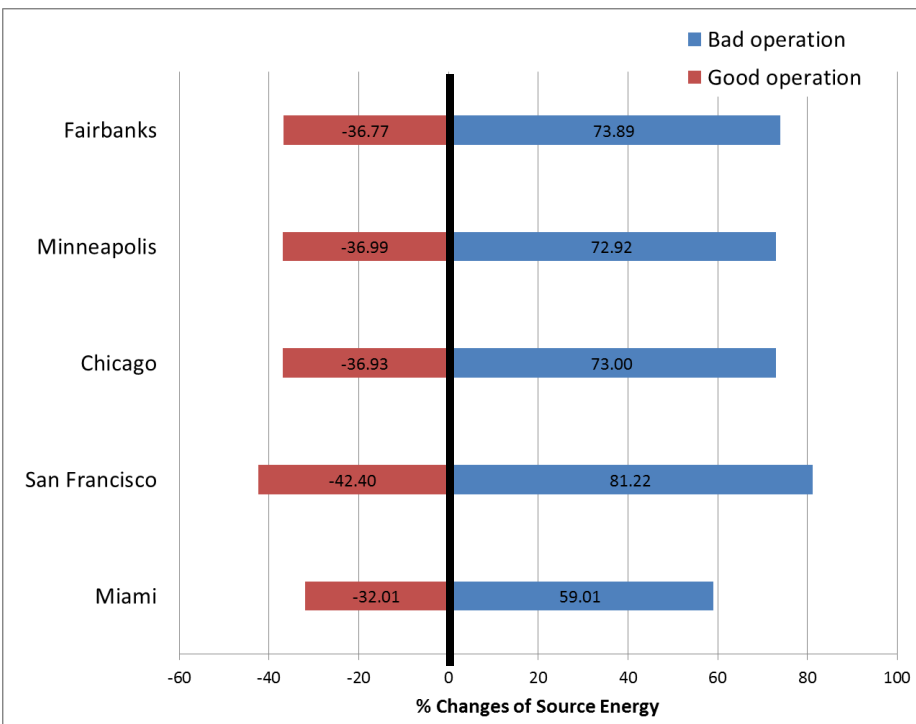Minneapolis (Source Energy EUI of Basecase 1.42 GJ/m²)

San Francisco (Source Energy EUI of Basecase: 1.27 GJ/m²)
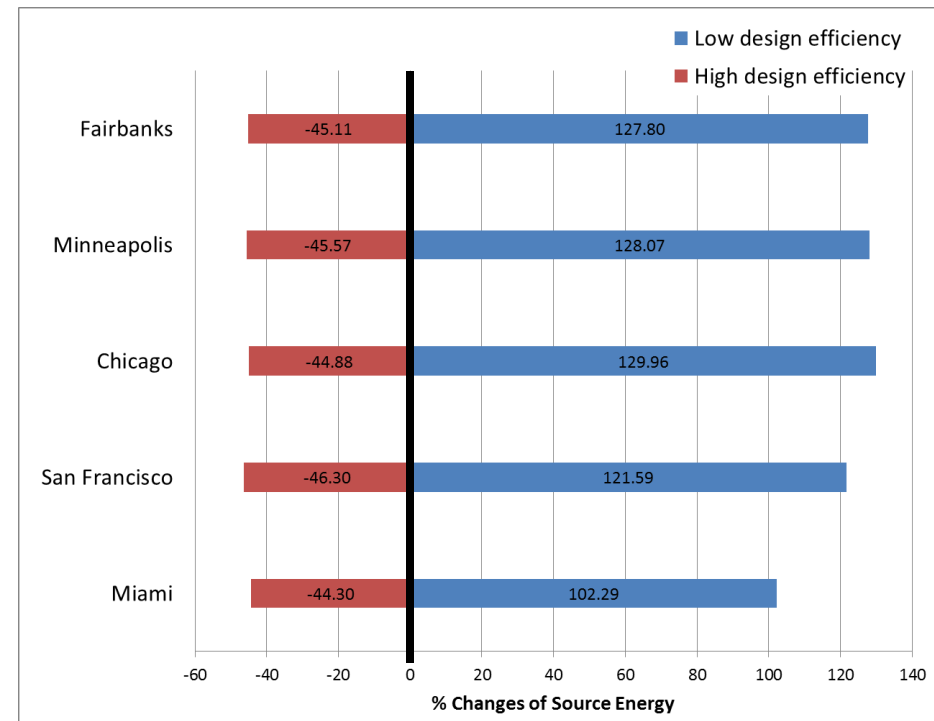
Climate Variability

Operation Impact by climate
- Basecase design efficiency

## Design Impact by climate
- Basecase operation

Operation Impact by climate chart — % Changes of Source Energy

Location	Good operation	Bad operation
Fairbanks	-36.77	73.89
Minneapolis	-36.99	72.92
Chicago	-36.93	73.00
San Francisco	-42.40	81.22
Miami	-32.01	59.01

Design Impact by climate chart — % Changes of Source Energy

Location	High design efficiency	Low design efficiency
Fairbanks	-45.11	127.80
Minneapolis	-45.57	128.07
Chicago	-44.88	129.96
San Francisco	-46.30	121.59
Miami	-44.30	102.29

30

Climate Variability

Best Case:

• Good operation and high efficiency design

Worst Case:

• Bad operation and low efficiency design
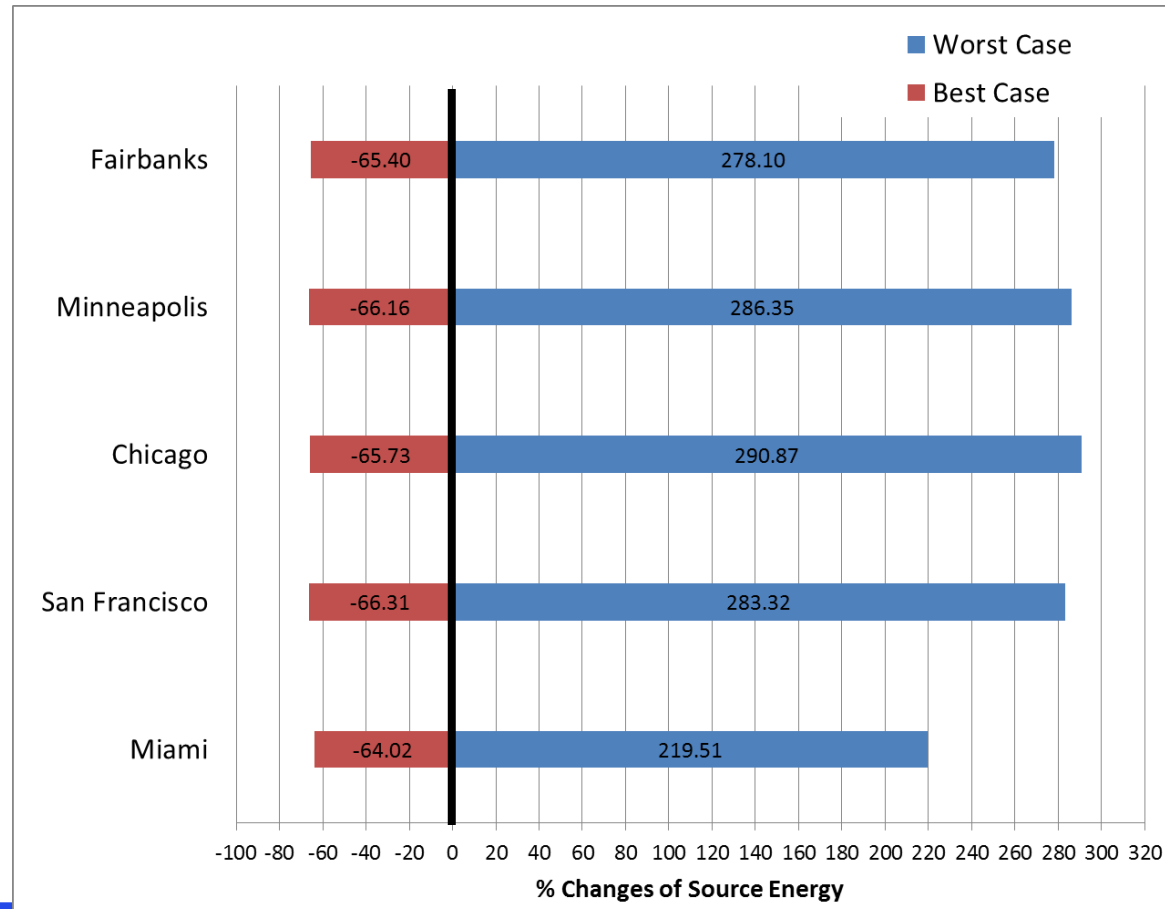
Conclusions

- Simulated source energy use varies in a wide range from -66% to + 290% depending on key building design and operation parameters

- Most influential parameters are internal loads (rates and schedules)

- Other influential parameters depend on climates, but generally include:
  - VAV box minimum position setting
  - Window (construction and area)
  - Economizer (hot climates)
  - Cooling setpoint temperature (hot climates)
  - Chiller efficiency (hot climates)
  - Cooling setback (hot climates)
  - Infiltration rate and schedule (cold climates)

Conclusions (Cont'd)

- Simulated source energy use varies from -6.5% to +6.5% when using weather data from historical years

- Building operation and occupants behavior related factors have significant impacts

- The range of simulation results between the Best and Worst cases overlap with most measured energy use of actual buildings

Occupant behavior analysis

Goal

- Identify key occupant behaviors related to energy use in private offices

- Quantify impact of occupant behavior on energy use

- Better understand how changes to occupant behavior can improve energy performance of buildings

Approach

- Determine most influential occupant behaviors:
  - Daylighting control, thermostat, HVAC operation hours, cooling startup control, occupancy controls (lighting, HVAC, plug-load)
- Categorize occupant behaviors into three types
  - Austerity
  - Standard
  - Wasteful
- Calculate and compare source/primary energy of individual offices
- Simulations:
  - Use a prototypical medium-size office building with efficiency levels based on ASHRAE Standard 90.1-2004
  - Select three typical climates (Miami, San Francisco, Chicago)
  - Use EnergyPlus Version 6 and TMY3 weather data

Building Prototype

N
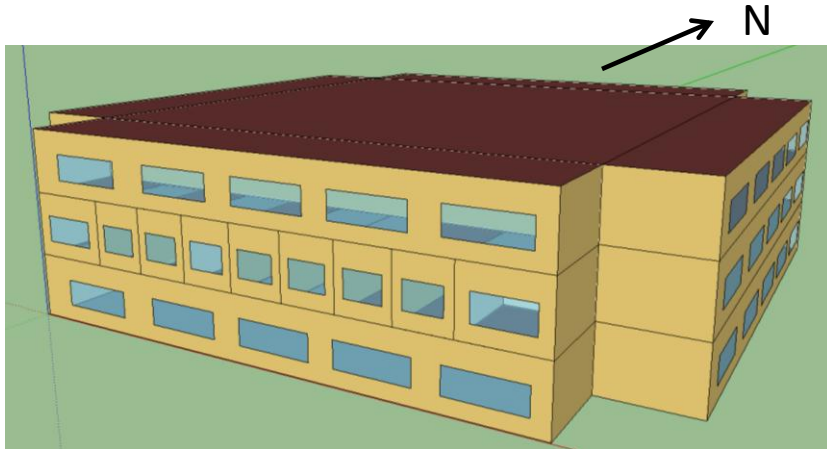
Whole building area: 4450 m²
Individual office area: 15 m²
Window to wall ratio: 21%
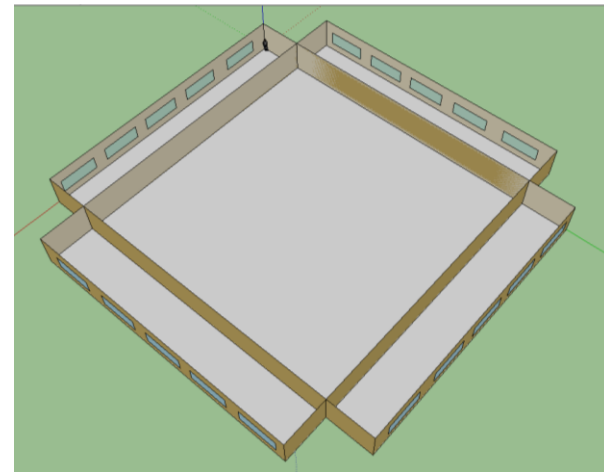**HVAC -**
Cooling   : PSZ-AC for individual offices
                       Central VAV for other zones
Heating   : Gas furnace for individual offices
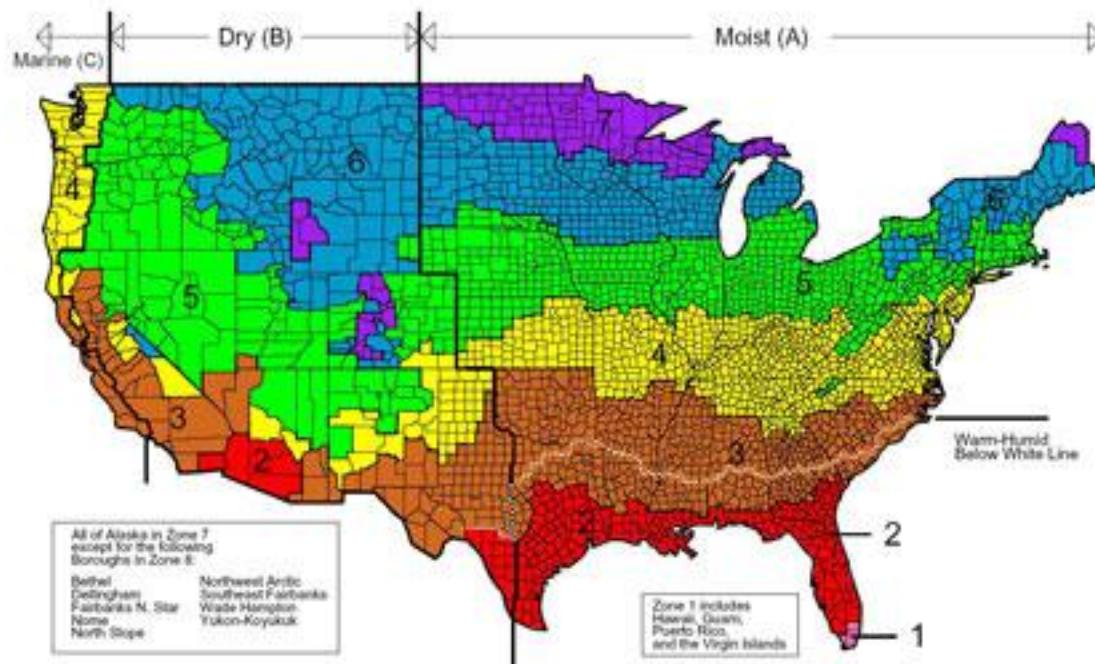   **Hot water boiler for other zones**
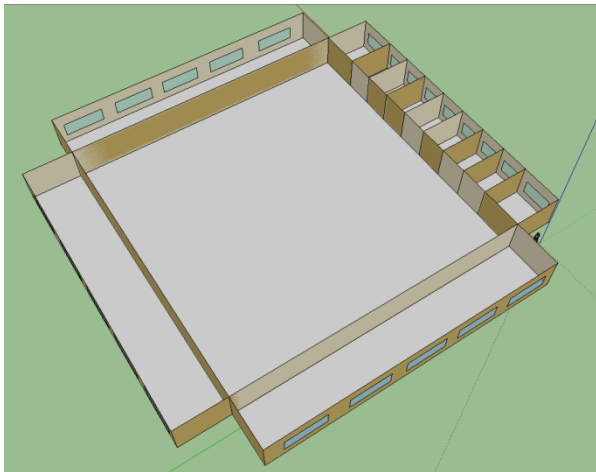
Mid Floor

Top and Bottom Floors
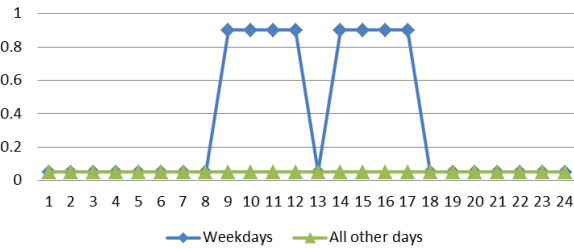
Selected Cities and Climates

City	ASHRAE Climate Zones		HDD18	CDD10
Miami	1A	Very Hot –Humid	200	9474
San Francisco	3C	Warm-Marine	3016	2883
Chicago	5A	Cool-Humid	6176	3251

ASHRAE Climate Zones
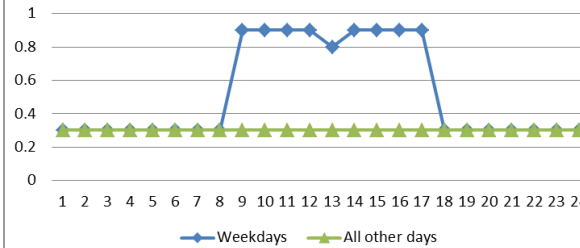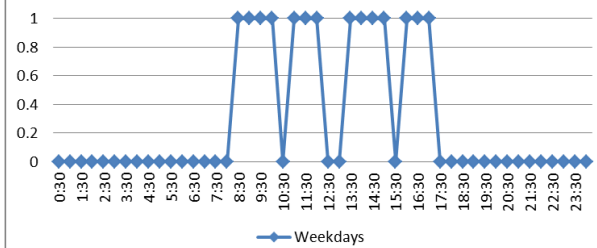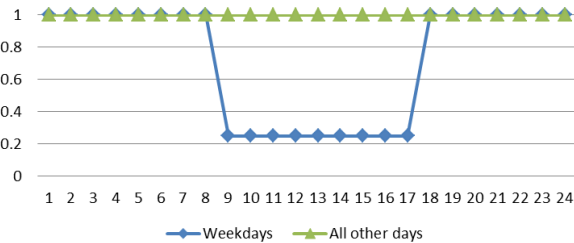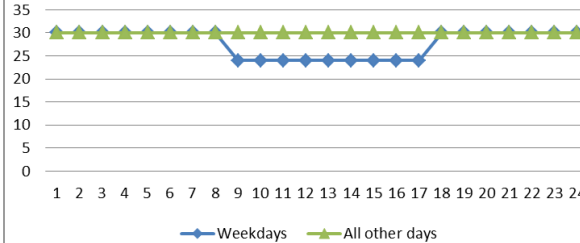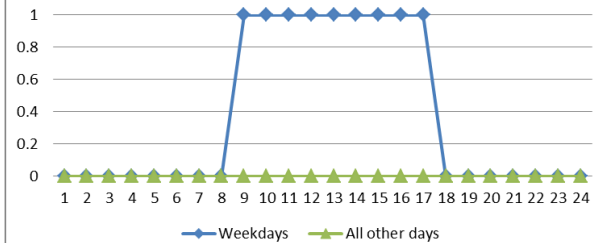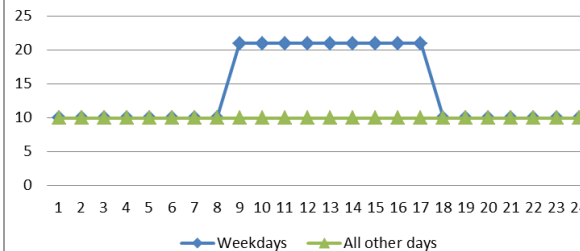
Modeling Parameters of Occupant Behavior

Behavior	Austerity	Standard	Wasteful
Cooling Setpoint (^{o}C)	26	24	22
Heating Setpoint (^{o}C)	18	21	23
HVAC Operation Time (Cooling and Heating)	9:00am - 4:00pm	8:00am - 5:00pm	6:00am - 10:00pm
Daylighting Control	Stepped Dimming (No. of Steps =3)	None	None
Adaptive Comfort	Yes	None	None
Occupancy Control	If unoccupied • Lighting: off • Plug-load: 30% off • HVAC: off	Scheduled	If unoccupied • Lighting: on • Plug-load: on • HVAC: on
Cooling Startup Control	Cooling starts when $T_{zone, air} \geq 28^oC$ during occupied hours, once started maintains the cooling setpoint; Cooling off during unoccupied hours.	Follow fan schedule & cooling thermostat during 8:00am - 5:00pm	Cooling always on during 6:00am - 10:00pm

Adaptive Comfort

Acceptable operative temperature ranges for naturally conditioned spaces (ASHRAE Standard 55-2010)
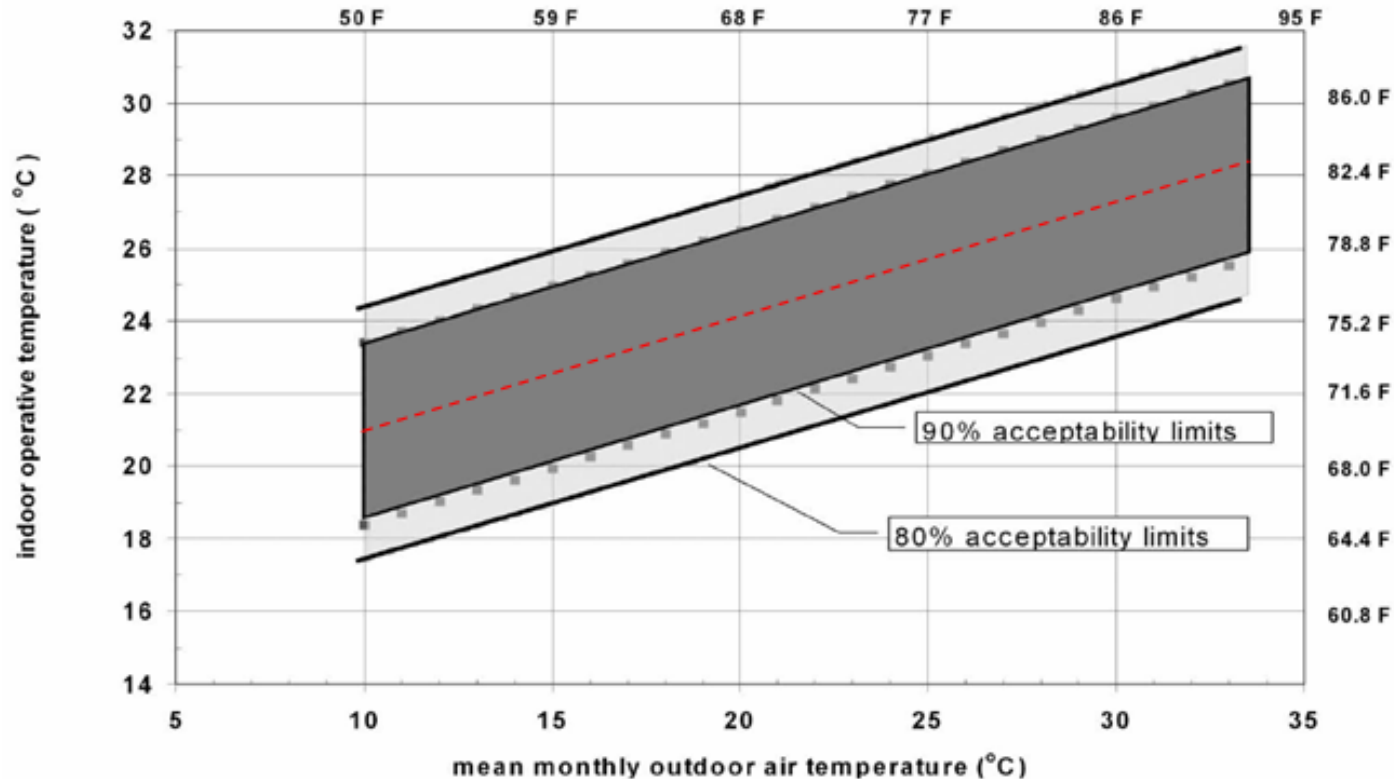
Comfort temperature

$$T_{ot} = 0.31*T_o + 17.8$$

Simulation Results

San Francisco, Source Energy EUI of Basecase : 1048 MJ/m^2

- Adaptive Comfort — Yes, None, None
- Occupancy Control — Unoccupied: lighting off, plugload 30% off, HVAC off
- HVAC Operation Time — 9~16, 8~17, 6~22
- Heating Setpoint — Temperature (^{o}C): 18, 21, 23
- Daylighting Control — Stepped dimming, None, None
- Cooling Setpoint — Temperature (^{o}C): 26, 24, 22
- Cooling Startup Control — On when occupied hours and room temp >28°C
- Austerity & Wasteful

% changes of source energy

Simulation Results

Chicago, Source Energy EUI of Basecase : 1314 MJ/m^2

% changes of source energy

Category	Settings
Adaptive Comfort	Yes, None, None
Occupancy Control	Unoccupied: lighting off, plugload 30% off, HVAC off
HVAC Operation Time	9~16, 8~17, 6~22
Heating Setpoint	Temperature (°C): 18, 21, 23
Daylighting Control	Stepped dimming, None, None
Cooling Setpoint	Temperature (°C): 26, 24, 22
Cooling Startup Control	On when occupied hours and room temp >28°C
Austerity & Wasteful	

Simulation Results

Miami, Source Energy EUI of Basecase : 1462 MJ/m^2

Chart — "% changes of source energy" (x-axis from -70 to 90)

Category	Annotation
Adaptive Comfort	Yes, None, None
Occupancy Control	Unoccupied: lighting off, plugload 30% off, HVAC off
HVAC Operation Time	9~16, 8~17, 6~22
Heating Setpoint	Temperature (^{o}C): 18, 21, 23
Daylighting Control	Stepped dimming, None, None
Cooling Setpoint	Temperature (^{o}C): 26, 24, 22
Cooling Startup Control	On when occupied hours and room temp >28°C
Austerity & Wasteful	

Conclusions

- **Occupant behavior has significant impact on building energy use**
  - Simulated source energy use for austerity and wasteful occupants varies in a wide range from -40% to +89% compared to the 'standard'
- **Cooling startup control is the most influential behaviors in terms of energy impact**
- **Cooling setpoint plays a more important role for hot climates**
- **Simply turning off lights and HVAC and turning down office equipment when unoccupied can save significant amount of energy**
- **Almost no cost to achieve energy savings from the austerity lifestyle**
- **Energy savings depend on HVAC system and climate zones**

Next Steps

- Refine modeling parameters of occupant behavior
- Look at other behaviors including:
  - Shading Control
  - Open and close windows
- Validate simulation results with field measurements and surveys

Thank You !

Contact information

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